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The Effect of Heavy-Duty Diesel Emission Standards on U.S. Army Ground Vehicles

SERDP (Strategic Environmental Research and Development Program) - 'Environmental Impact of Fuel Use on Military Engines'

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- **Fuels and Lubricants Discussion**
- **Current Army Ground Vehicle Engine Philosophy and Conclusion**

Conclusion

- The Army can not buy 2007 compliant COTS engines and directly integrate into current and new heavy-duty vehicles.

Introduction to Army Ground Vehicles

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Representative Army Ground Vehicles

COMBAT VEHICLES

- M1 Abrams (AGT-1500)
- M109/M110 Self Propelled Howitzer (8V71T)
- M2/M3 Bradley (VTA-903)
- M88 Medium Recovery Vehicle (TCM-1790)
- M578 – Light Armored Recovery Vehicle (LRC) – (8V71T)
- M60 family (TCM-1790)
- Chaparral Missile Launcher (6V53T)
- FAASV – Fast Assault Ammunition Supply Vehicle (8V71T)
- M551 Sheridan Assault Vehicle (6V53T)
- Stryker (3126)
- MRAP Mine Resistant Ambush Protected (ITEC I6)

TACTICAL VEHICLES

- HET Heavy Equipment Transporter (8V92TA)
- HEMTT Heavy Expanded Mobility Tactical Truck (8V92TA)
- PLS Palletized Loading System (8V92TA)
- 2.5 Ton Truck (LD-465/LDT-465)
- M939 5 Ton Truck (NHC 250/6CTA8.3)
- M915/M916 Line Hauler (NTC400/S-60)
- M917, M918, M919 Tractor (NTC 400)
- HMMWV (GM 6.2/6.5 IDI)
- CUCV Commercial Utility Cargo Vehicle (GM 6.2/6.5 IDI)
- FMTV Family of Medium Tactical Vehicles (C7)

LEGEND: **red: two-stroke diesel** **white: four-stroke diesel** **yellow: gas turbine**

Army Ground Vehicles

300,000 + **tactical and combat vehicles (150 – 1500 BHP)**

240,000 + **trucks – class 2 thru class 8 + (150 – 500 BHP)**

40,000 + **2-stroke powered vehicles (200 – 500 BHP)**

M113 Personal Carrier

PLS – Palletized Loading System

MRAP - Mine Resistant Ambush Protected

HEMTT – Heavy Expanded Mobility Tactical Truck

*FVPDS (Jan. 2000)

Fielded Vehicle Performance Data Systems

Army Ground Vehicle Propulsion Challenges

‘Traditional Issues’

1. Cooling
2. Fuel Effects
3. Filtration

Evolving Need for Better Protection, i.e. More Weight

1. Cooling
2. Sluggish Mobility

The Army vehicle cooling point is high tractive effort to weight under desert-like operating conditions (ex. 5 ton wheeled vehicle ~0.6 while 15+ ton tracked vehicle ~0.7 both at 120 F ambient or higher)

Overview Heavy-Duty Diesel Emission Standards

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Regulatory Approach (2007)

EPA finalized motor vehicle diesel fuel regulations and the heavy duty diesel *on-road* exhaust emissions regulations in January 2001.

Took a dual approach to reduce air emissions by:

1. Reduction in diesel fuel sulfur concentration to 15ppm starting June 2006.
   - Enable the use of exhaust system aftertreatment devices
   - **JP-8 specification calls for < 3000 ppm!**
2. Establish stringent exhaust emission standards - effective **2007.**
   - Phased-in approach; fully meet standards in **2010**
   - Require aftertreatment device(s)
     - Particulate filters in 2007
     - NOx aftertreatment 2010 (traps or urea SCR)

(Both regulations implemented with a phased approach)

Off-road standards similar in nature and 'lag' on-road standards by approximately three years depending on engine rated power

Potential Impacts to DoD

- **Ground tactical vehicles (i.e. HEMMT, PLS, HMMWV) operating in the U.S. required to meet the fuel 15 ppm sulfur regulation**
  - JP-8 does not meet this requirement (specification < 3000 ppm)

- **Procure vehicles with pollution control technology**
  - Potential performance degradation (fuel consumption, reliability, durability)
  - The current leading pollution control technology candidates are intolerant of high sulfur fuel
  - Significant increase in vehicle thermal load

- **Nebulous world wide operation since low sulfur fuel is not available world wide:**
  - Low sulfur diesel fuel is an enabler for pollution control devices

(Combat vehicles (i.e. Abrams, Bradley, Stryker) are automatically exempt under 40 CFR, 89.908)

DoD Interaction with EPA

- **EPA approved NSE request for JP-8 exclusion from on-road 2006 and off-road 2007 diesel fuel regulations**
- **'Blanket NSE' granted from meeting 2007+ heavy-duty, on-road emission standards (August 23, 2005)**
- **'Blanket NSE' granted from 2004 on-road emission standards (November 15, 2006)**
- **Off-Road equipment Tier IV emission standards NSE submitted to the EPA**

Emission Control Technology Discussion

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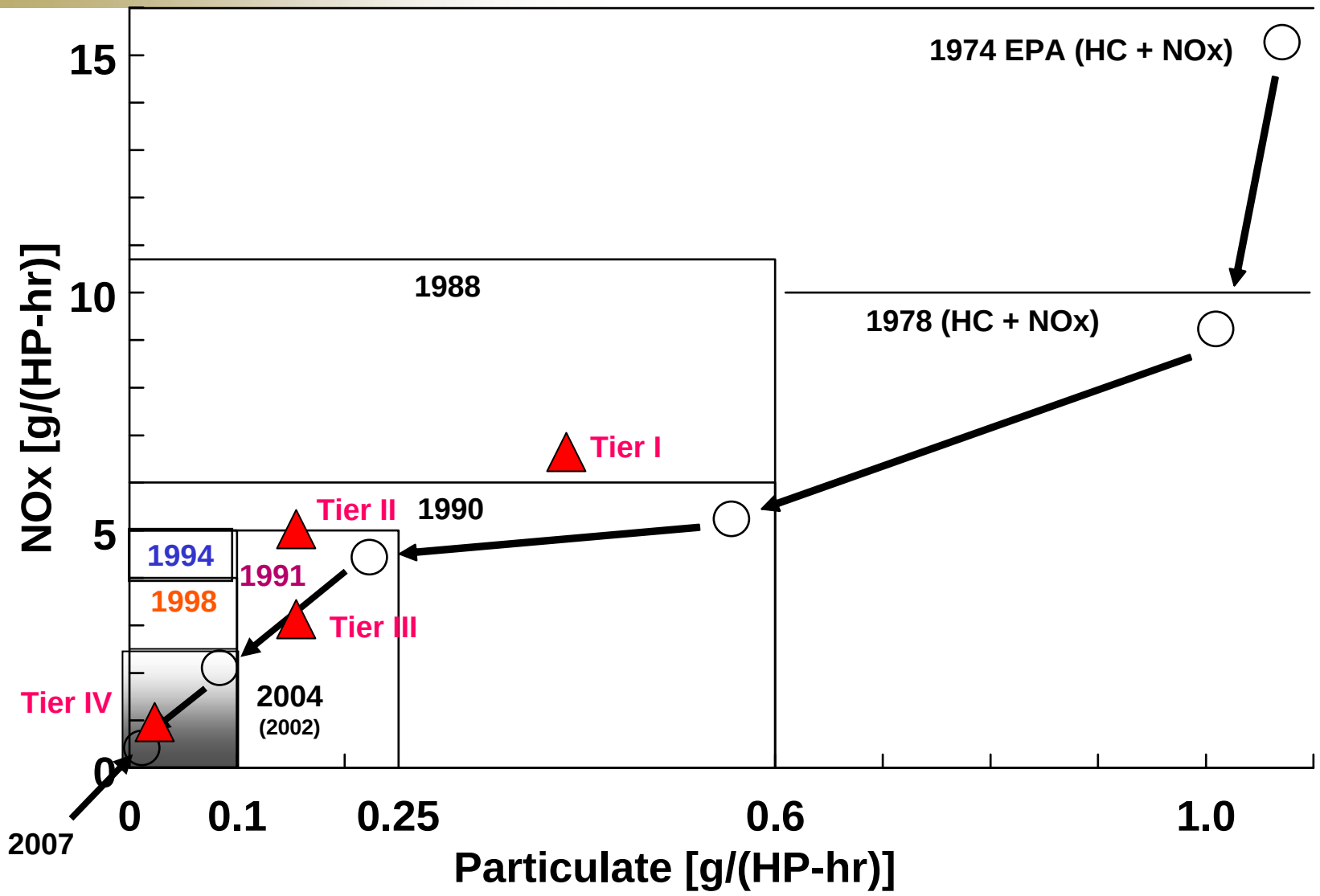
On-Road Versus Off-Road HD Standards (300 – 600 BHP)



On-Road Emission Standards

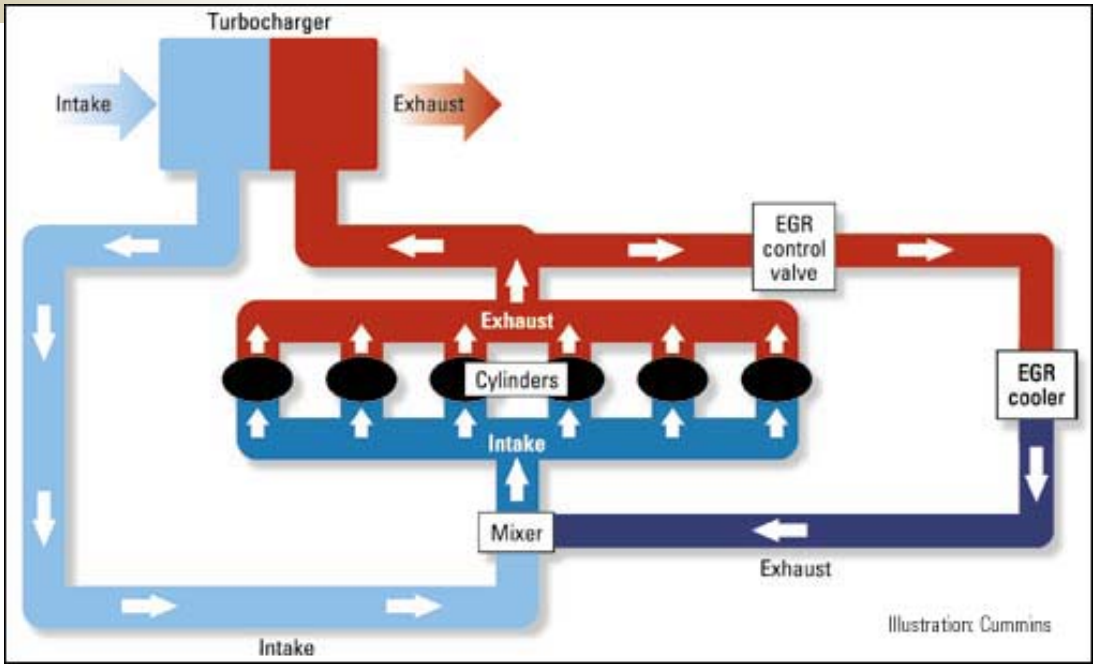
Impact of 2004 Standards on Commercial Heavy-Duty Diesel Engines

- **C**ooled **E**xhaust **G**as **R**ecirculation (**EGR**)
- **ACERT™** – **A**dvanced **C**ombustion and **E**missions **R**eduction **T**echnology

Impact of 2007 Emission Standards on Commercial Heavy-Duty Diesel Engines

- **C**ooled **E**xhaust **G**as **R**ecirculation (**EGR**) with advanced combustion and closed-loop engine system controls
- **ACERT™** – **A**dvanced **C**ombustion and **E**missions **R**eduction **T**echnology plus aftertreatment (catalytic converter) and closed-loop engine system controls along with low pressure and ‘filtered’ EGR loop
- New combustion regimes that may require specified fuel properties
- *High Pressure Common Rail fuel systems that require a lubricity additive through a slow dosing fuel filter (OEMs need more flexible fuel systems for multiple event, high pressure fuel injection)*

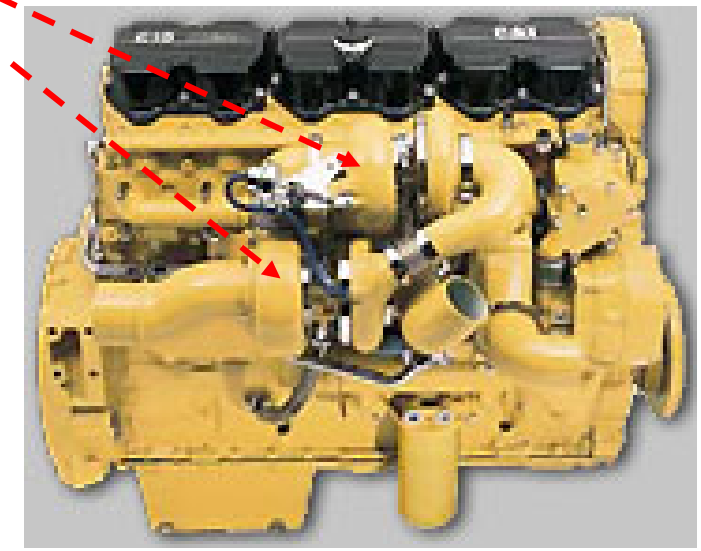
What is cooled EGR? (High Pressure)



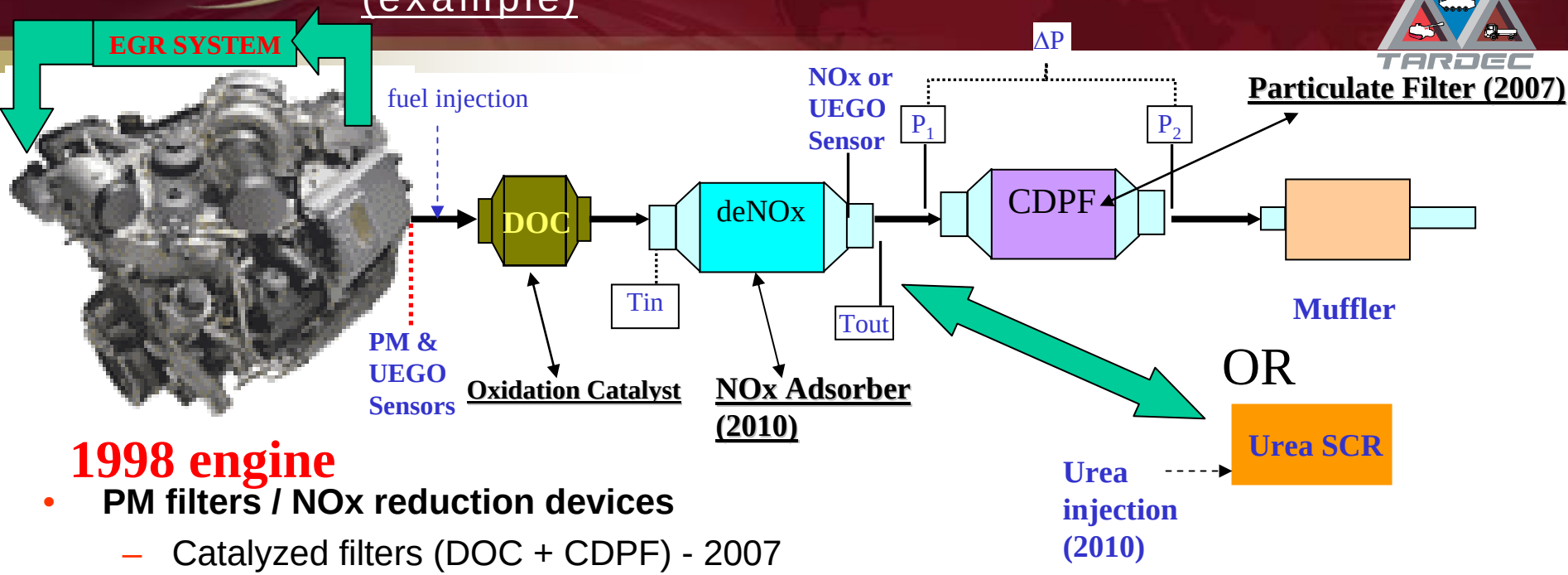
- Reduce nitrous oxides (NO_x) through 'cooler' combustion temperatures
- Recirculate and cool exhaust gas downstream of turbine (turbocharger) ; require back pressure restriction to flow exhaust gas to intake system **(fuel economy penalty)**
- **Cool exhaust gas** before dumping into intake system; **additional engine system cooling requirement)**; non-ram air scenarios will have additional fuel economy penalty
- Temperature control of EGR crucial in order to avoid formation of **sulfuric acid that expedites engine wear and reduces durability of EGR cooler and control valve**
- This concept introduces particulates into cylinder ; **requires more frequent oil change w/o certification of proper lubricant**

What is ACERT™?

- Caterpillar trademark non-EGR solution
- Limited variable intake valve timing ; **extra valve train sophistication**
  - **'cooler' combustion temperatures**
- **Two stages of turbocharging (single stage for smaller displacement engines)**
- **Additional charge air cooling necessary** ; increase in required engine system heat rejection – **not as significant impact as cooled EGR**
- **Passive oxidation catalyst** (catalytic converter) and **diesel particulate filter (DPF)** in some applications along with **low pressure EGR** on 2007 MY applications



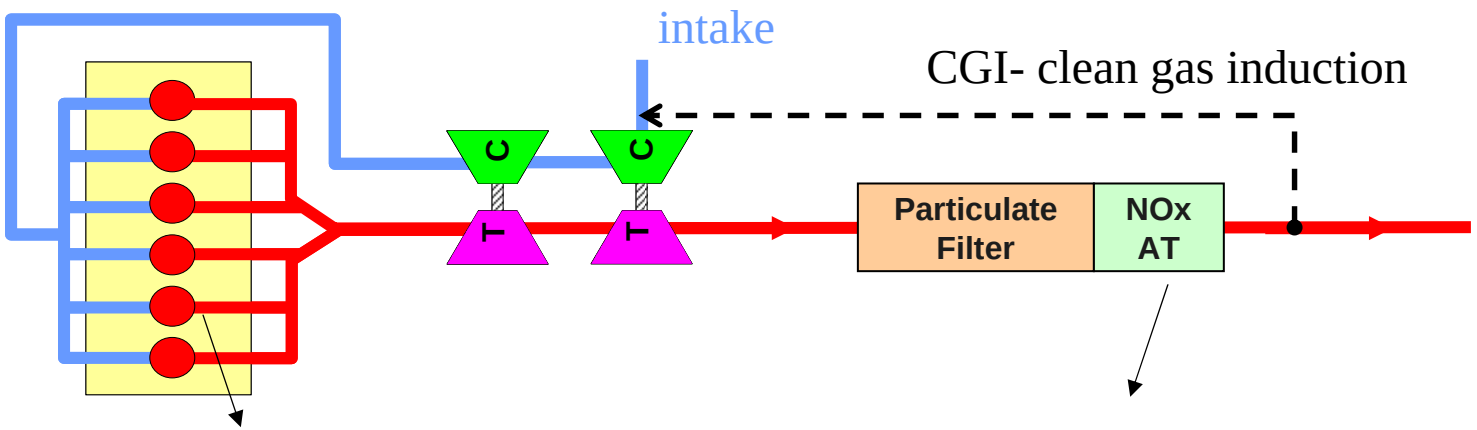
2007 Emission Issues : Aftertreatment Devices (example)



1998 engine

- **PM filters / NOx reduction devices**
  - Catalyzed filters (DOC + CDPF) - 2007
  - NOx trap (adsorber) vs. Urea SCR (selective catalytic reductant) – 2010
  - Additional space claim , **conservatively 2.5 - 5 times the engine displacement**
- **NOx trap requires 15 ppm fuel sulfur level**
- Likely to include high levels of EGR in additional to NOx aftertreatment device
  - higher heat rejection (~ 50% increase vs. MY1998)
- Push toward new oil formulation to extend CDPF lifetime
- Urea SCR requires on-vehicle, urea storage tank and 'safeties' to ensure vehicle operator compliance; urea quality sensor, cold weather freeze avoidance, empty tank precautions

Potential ACERT Solution



Engine NOx Technology

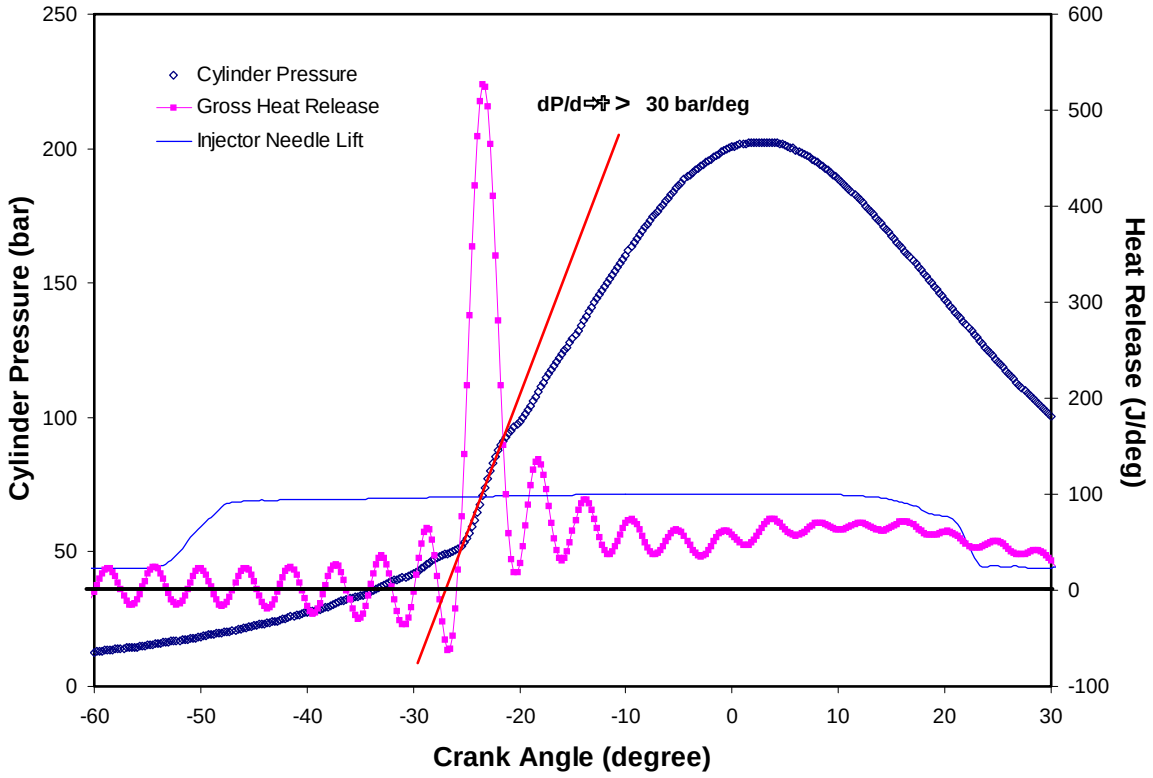
- Advanced Diesel Combustion

Aftertreatment NOx Technology Options

- DeNOx Catalyst
- NOx Adsorber
- Urea SCR

New Combustion Regimes

- High Pressure Rise Strategies: HCCI, PCCI, etc.
  - fuel ignition quality and evaporation characteristics important
  - JP-8 ‘loose’ property specifications, i.e. CN dependent on supply source



Fuels and Lubricants Discussion

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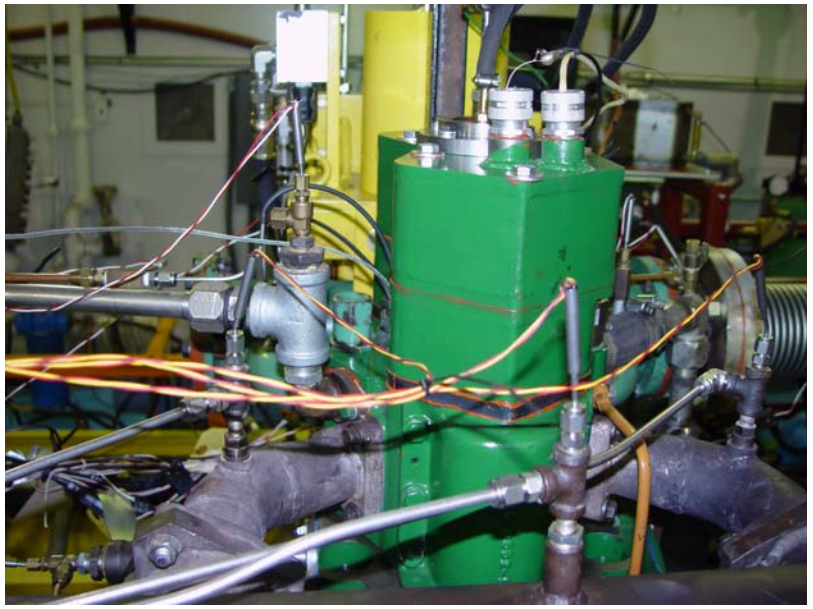
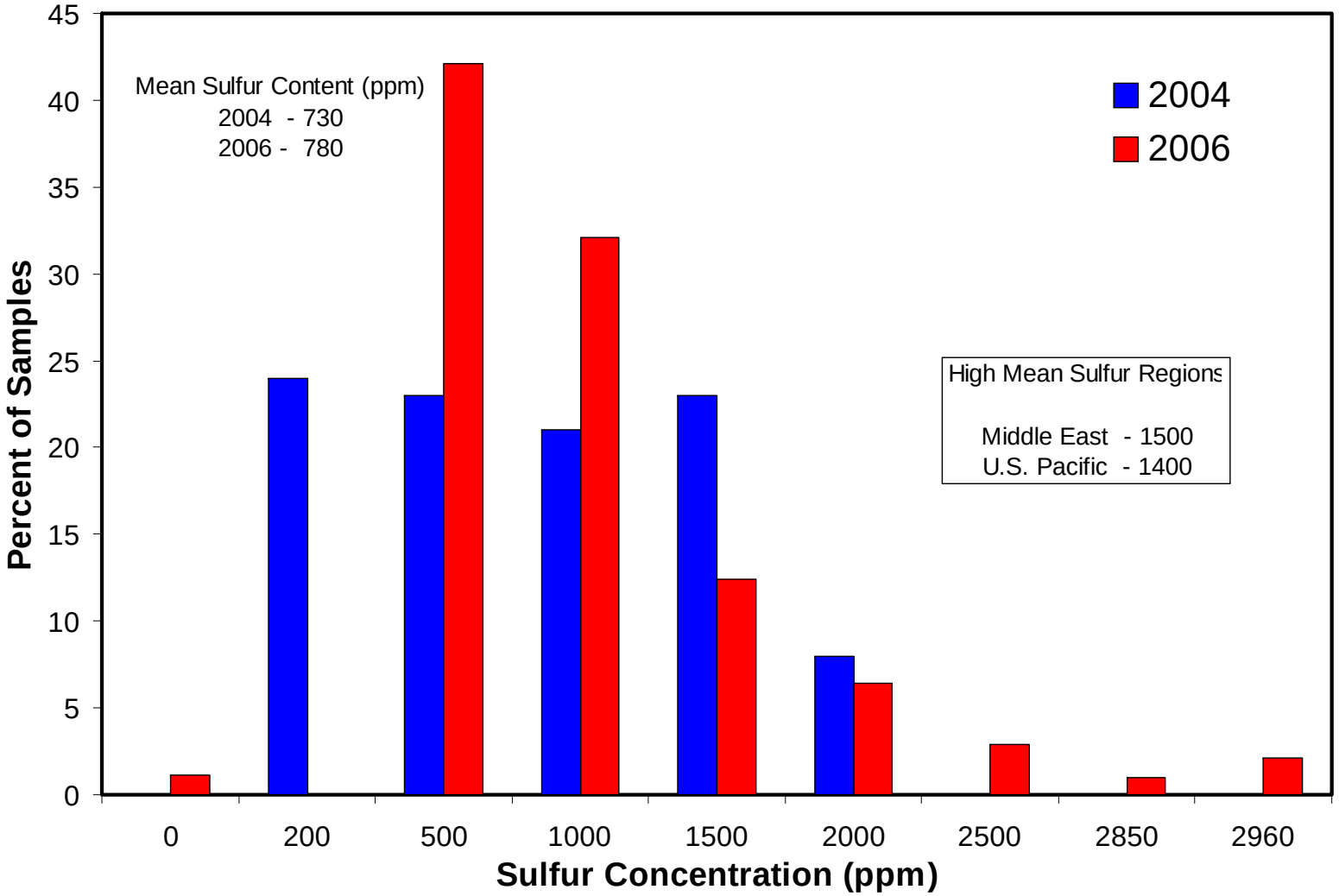
JP-8 Property Specifications

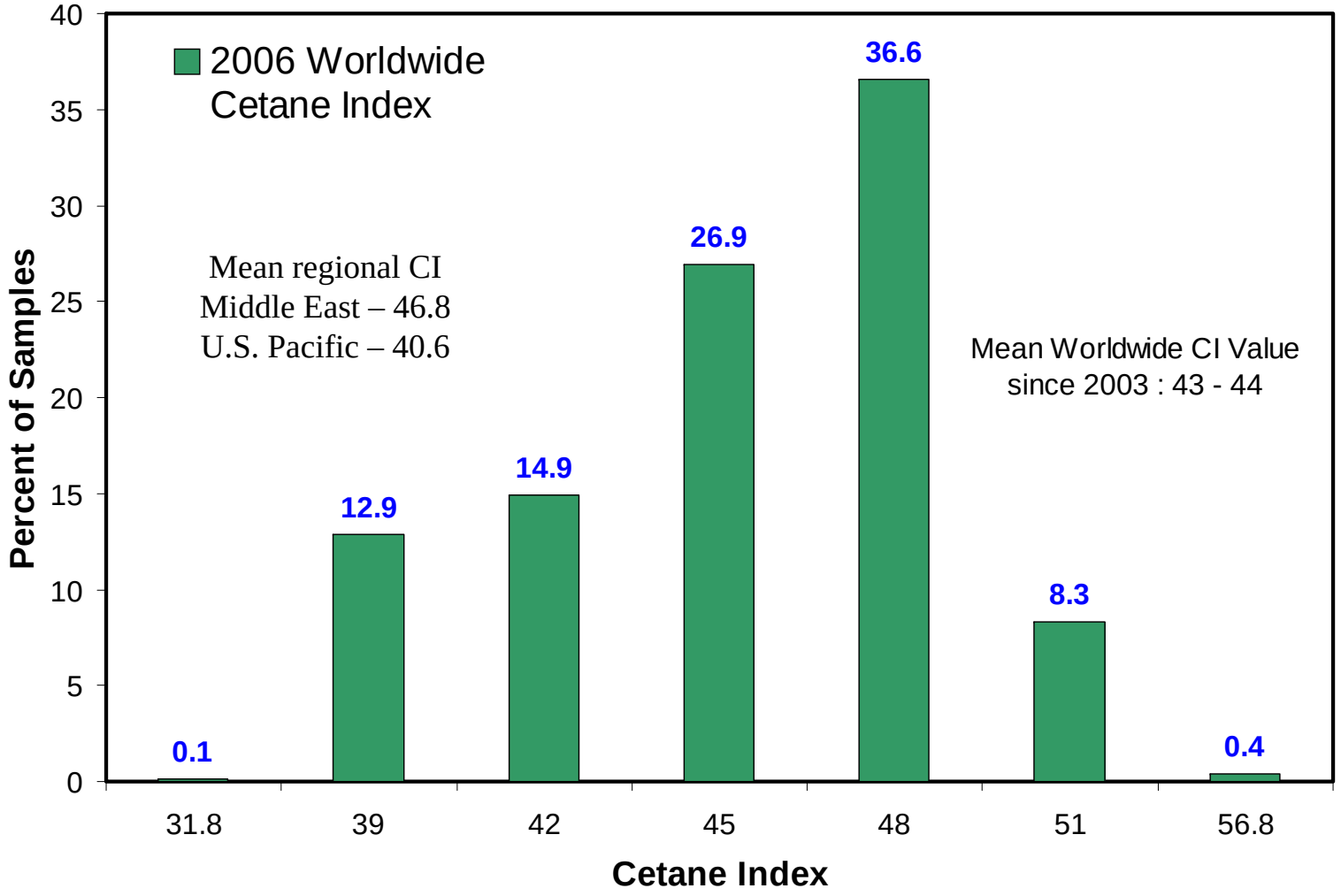
- **Sulfur content: max. 3000 ppm**
- Aromatics: max. 25%
- Specific gravity: 0.775 – 0.84
- Evaporation Characteristics:
  - 10% recovery: max. 205 C (186 C)
  - End point: max. 300 C (330 C)
- Net Heating Value: min. 42.8 MJ/kg
- **Cetane Index: none**



JP-8 Fuel Sulfur Content Example: Worldwide

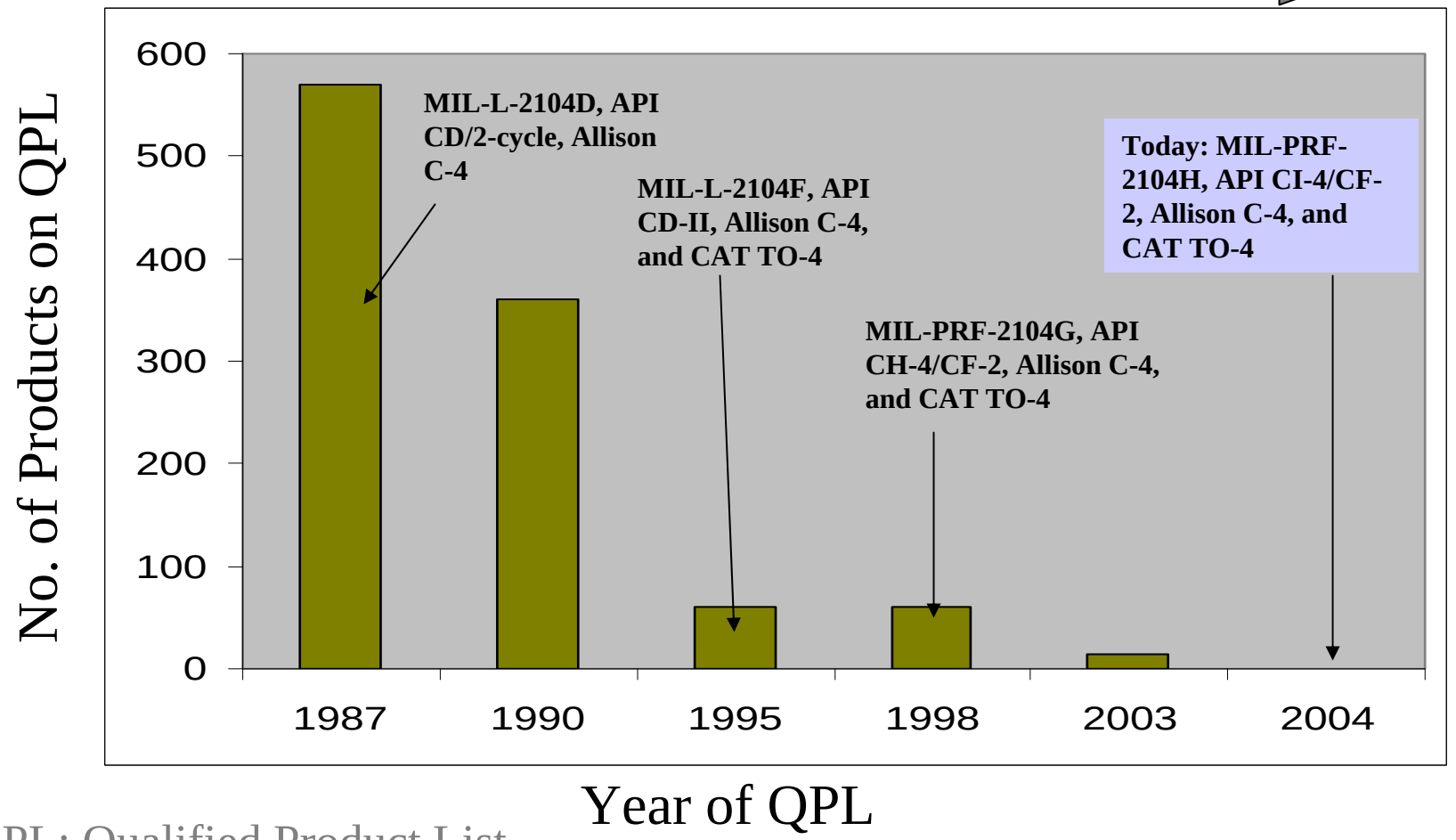


JP-8 Cetane Index Worldwide Trend in 2006



Impact of Emission Standards on Military Heavy-Duty Diesel Engine/Transmission Oils (E/TO)

Increasing performance and test costs



QPL: Qualified Product List

Impact of Emission Standards on Military Heavy-Duty Diesel Engine/Transmission Oils (E/TO) – Performance concerns

- US Market Drivers for lubricants
  - Ultra-low-sulfur fuels (ULSF)
  - Compatibility with pollution prevention devices (toward low ash, phosphorus, and sulfur concentrations)

- Some additive technologies proven to work well with higher sulfur fuels will not be allowed in the future
  - Additives with phosphorus and ZDDP (zinc dialkyl dithiophosphate)
  - Due to 'poisoning' of pollution devices

- Military exposure to high sulfur fuels raises concerns regarding engine protection with lubricant technology developed around ULSF
  - Logistic and Maintainability concerns

- Unknown impact of future engine oils on transmission performance
  - No commercial interest.

Solution Pathways – Short Term to 2004 Heavy-Duty On-Road Emission Standards

- EGR Engines
  - Issues: increased heat rejection and system volume, fuel and lubricant compatibility (reliability and durability issues)
  - Solution: employ EPA granted NSE, remove EGR system, recalibration of engine to meet military performance demands

- Non-EGR Engines
  - Issue: JP-8 compatibility and thermal management system requirements
  - Solution: ensure JP-8 compatibility with engine system and compliance with military performance demands; ensure thermal management system meets vehicle requirements

Current Army Ground Vehicle Engine Philosophy and Conclusion

Solution Pathways – Long Term to 2007/2010 Heavy-Duty On-Road Emission Standards

- All engine systems have or are head toward some type of aftertreatment system with advanced combustion strategies and closed loop control
  - NOx trap, catalyzed filters (CDPF/DOC), urea or fuel based SCR
  - HCCI, PCCI, and other more 'homogeneous combustion modes'
  - LTC : low temperature combustion for light loads, possible regeneration strategy
  - **Heavy use of cooled EGR (>50% heat rejection increase vs. MY 1998)**
    - possible low pressure cooled EGR in some cases
  - Exhaust sensors for temperature(s), pressure(s), NOx concentration, O_2 concentration, ammonia, urea
    - Closed loop control package for monitoring and regenerating aftertreatment devices
  - **Commercial diesel fuel properties may require tighter combustion related property specifications for advanced combustion system operating modes**

Solution Pathways – Long Term to 2007/2010 Heavy-Duty On-Road Emission Standards

- Engine systems **must be modified** to meet military requirements
  - Use of blanket NSE for MY 2007+ engine systems
  - Removal of EGR system
  - Removal of aftertreatment devices
  - Recalibration
  - Ensure high sulfur fuel tolerant and oil compatible components
  - **Unknown on how to handle fuel lubricity filter technology**

Conclusion

- The Army can not buy 2007 compliant COTS engines and directly integrate into current and new heavy-duty vehicles.

THANKS!